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The Cryogenic Tensile Properties of an Extruded Aluminum-Beryllium Alloy

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X–38 Bolt Retractor Subsystem Separation Demonstration

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BRS	bolt retractor subsystem
DPS	deorbit propulsion stage
fps	frames per second
FRL	Flight Robotics Laboratory
lbf	pounds force
LED	light-emitting diode
LMB	Large Mobility Base
LRF	laser rangefinder
LVDT	linear variable displacement transformer
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
PSF	Pyrotechnic Shock Facility
SMB	Small Mobility Base

NOMENCLATURE

k	spring stiffness
m	mass
t	time
x	displacement
x_0	initial displacement
x_{ic}	displacement of spring at point of interface crossing
τ_{ic}	time of interface crossing
ω	natural frequency

TECHNICAL MEMORANDUM

THE CRYOGENIC TENSILE PROPERTIES OF AN EXTRUDED ALUMINUM-BERYLLIUM ALLOY

1. INTRODUCTION

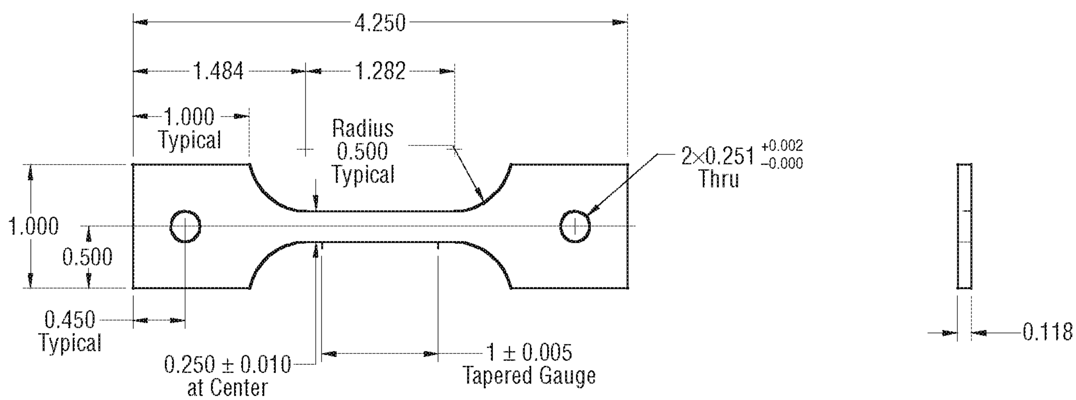
Aluminum (Al)-beryllium (Be) materials have been around for some time, beginning with the material developed in the 1960s by Lockheed called “Lockalloy.”[1] Interest in their use waned in the 1970s and the materials became unavailable. In the past decade, due to the desirable performance characteristics of this family of composite materials for aerospace applications, new alloys have been developed with improved mechanical properties, along with improved processing techniques and process controls for their production. Al-Be materials are available in the form of extrusions, rolled plate, forgings, and most recently, near-net-shaped investment castings.

Desirable characteristics of Al-Be materials include lightweight, dimensional stability, stiffness, good vibration-damping characteristics, low coefficient of thermal expansion, and workability.[1] These materials are 3.5 times stiffer and 22-percent lighter than conventional Al alloys. Their use is attractive for weight-critical structural applications such as advanced electro-optical systems; advanced sensor and guidance components for flight and satellite systems; components for lightweight, high-performance aircraft engines; and structural components for helicopters. As these materials become more highly used in aerospace programs, mechanical properties at liquid hydrogen temperatures will be needed for structural analyses. These properties are currently not available for these families of alloys.

AlBeMet162 is an Al-Be extruded alloy that was developed by the Brush Wellman Company.[1] It is currently being used on the telescope for the Next-Generation Space Telescope program for its desirable properties. The cryogenic tensile properties for this alloy were evaluated for Goddard Space Flight Center.

2. EXPERIMENTAL PROCEDURE

Tensile specimens were obtained from the Brush Wellman Company and fabricated per figure 1 from extruded AlBeMet162 material per SAE–AMS7912, "Aluminum-Beryllium Alloy, Extrusions."[2] The extrusion used to extract the specimens was approximately 2 by 8 by 35 in. Test specimens were extracted from the extrusion in the longitudinal (L), long-transverse (L–T), and 45° (45) orientations, and from the T/6, T/2, and 5T/6 locations (T = material thickness) along the length of the extrusion as shown in figure 2.



Notes:

1. The ends of the reduced section shall differ by not more than 0.002 in: there must be a gradual taper in width from the ends to the center (0.005 in max)
2. Holes must be on centerline of reduced section within ±0.002 in
3. Break all edges 0.005 in max
4. Do not undercut 0.005 in rad
5. These are final part size dimensions in inches.

Figure 1. Tensile specimen.

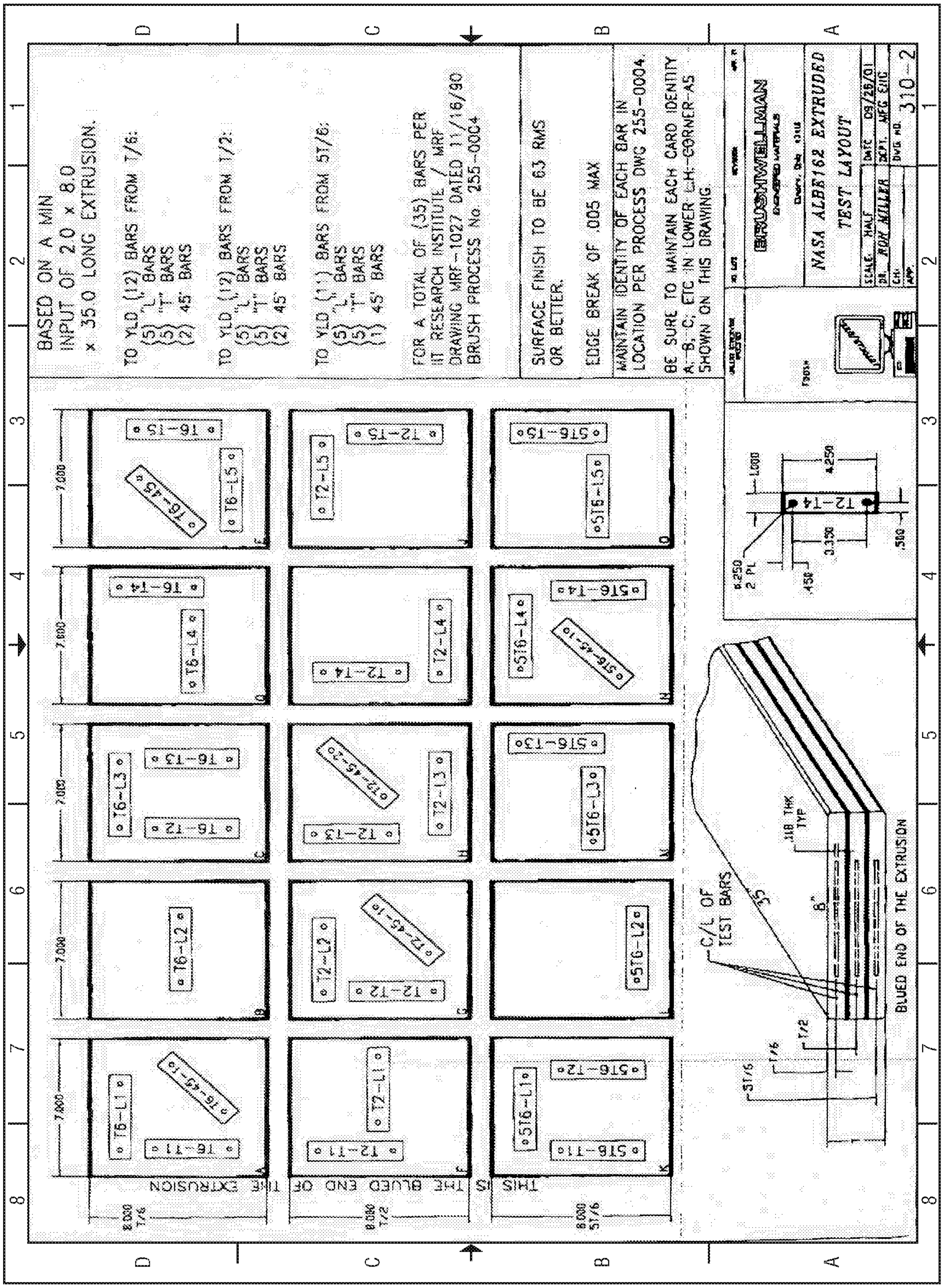


Figure 2. Extruded AlBeMet162 test specimen layout.

Twelve specimens were extracted from the T/6 location along the length of the extrusion—five with the L orientation, five with the L–T orientation, and two with the 45° orientation. Twelve specimens were extracted from the T/2 location along the length of the extrusion—five with the L orientation, five with the L–T orientation, and two with the 45° orientation. Eleven specimens were extracted from the 5T/6 location of the extrusion—five with the L orientation, five with the L–T orientation, and one with the 45° orientation (fig. 2). The different orientations were tested to determine whether a significant difference in the mechanical properties was discernable at cryogenic temperatures.

Tensile testing was performed at room temperature, at –195.5 °C (–320 °F) and at –252.8 °C (–423 °F). Room-temperature testing was performed to verify mechanical properties' conformance of the material to those specified in AMS7912. Cryogenic testing was performed to characterize the material properties; i.e., ultimate tensile strength, yield strength, percent elongation, and modulus, at the subject temperatures.

3. RESULTS

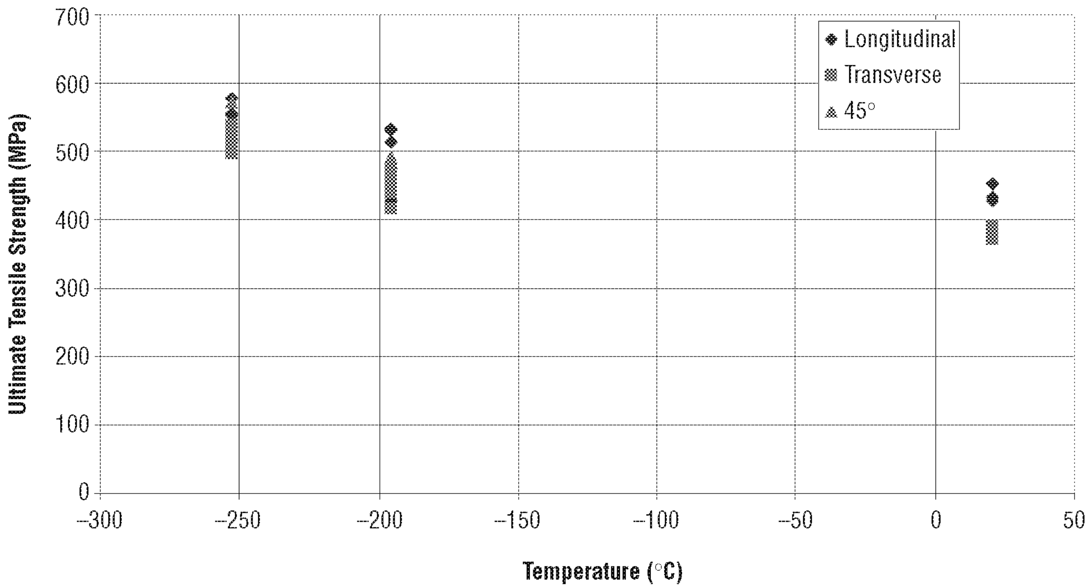
Mechanical property results are shown in tables 1 and 2 and figures 3–5. The means of the ultimate tensile and yield strengths and percent elongation for each temperature and specimen orientation are shown in table 3. Analysis of variance (ANOVA) results are shown in table 4. ANOVA was conducted for comparison of differences between the longitudinal and transverse specimens at –195.5 °C (–320 °F) and –252.8 °C (–423 °F), and for comparison of differences between properties of the same specimen orientation at different temperatures.

Table 1. AlBeMet162 tensile data at room temperature, –195.5 and –252.8 °C.

Other ID No.	Orientation	Test Type	Temp. (°C)	0.2% Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elastic Modulus (GPa)	1-in Elongation (%)	Plastic Elongation (%)	Total Elongation (%)
T6L1	L	Tensile	21	331.8	451.3	175.8	–	8.1	8.2
T2L5	L	Tensile	21	316.5	432.0	172.4	–	7.4	7.6
5T6L3	L	Tensile	21	317.8	426.8	180.0	–	6.3	6.5
5T6T4	T	Tensile	21	317.5	377.2	155.8	–	2.3	2.5
T6T5	T	Tensile	21	318.2	389.9	171.7	–	2.4	2.6
T2T3	T	Tensile	21	312.3	372.3	165.5	–	2.4	2.6
T6–45–1	45	Tensile	–195.5	310.3	456.4	237.9	2.7	2.5	2.7
T2–45–1	45	Tensile	–195.5	327.5	492.3	175.1	3.8	3.9	4.2
T6L2	L	Tensile	–195.5	362.7	530.2	176.5	3.1	3.3	3.6
T6L5	L	Tensile	–195.5	366.1	533.7	180.0	3.4	3.3	3.6
T2L3	L	Tensile	–195.5	347.5	515.0	216.5	3.1	3.1	3.3
5T6L1	L	Tensile	–195.5	355.1	475.7	186.8	2.9	1.9	2.2
5T6L4	L	Tensile	–195.5	384.0	427.5	188.2	0.6	0.8	1
T2T4	T	Tensile	–195.5	342.0	452.3	161.3	1.7	1.5	1.8
5T6T2	T	Tensile	–195.5	347.5	439.9	183.4	1.5	1.4	1.6
5T6T5	T	Tensile	–195.5	347.5	464.0	171.7	1.7	1.7	1.9
T6T3	T	Tensile	–195.5	346.8	475.7	189.6	2.0	1.8	2
T2T1	T	Tensile	–195.5	333.7	417.1	169.6	1.4	0.9	1.1
T2–45–2	45	Tensile	–252.8	439.2	536.4	176.5	1.5	1.06	1.36
T6–45–2	45	Tensile	–252.8	460.6	572.3	157.9	0.7	1.26	1.63
5T6–45–1	45	Tensile	–252.8	392.3	521.2	201.3	1.2	1.58	1.83
T6L3	L	Tensile	–252.8	474.4	537.1	175.1	–	0.62	0.92
T2L1	L	Tensile	–252.8	443.3	517.8	168.2	0.5	0.73	1.03
T2L4	L	Tensile	–252.8	450.2	578.5	221.3	1.3	1.44	1.7
5T6L2	L	Tensile	–252.8	440.6	528.8	200.6	0.8	0.88	1.15
5T6L5	L	Tensile	–252.8	477.1	554.3	159.3	1.1	0.92	1.26
T6L4	L	Tensile	–252.8	404.7	577.8	157.2	2.6	2.95	3.15
T2L2	L	Tensile	–252.8	462.6	553.6	184.1	1.1	1.05	1.3
T6T4	T	Tensile	–252.8	426.8	501.2	176.5	0.8	0.69	0.96
T2T5	T	Tensile	–252.8	433.7	512.3	158.6	–	0.64	0.96
5T6T3	T	Tensile	–252.8	433.0	521.9	199.3	0.8	0.75	1
T6T1	T	Tensile	–252.8	434.4	539.9	188.2	1.3	0.89	1.17
T2T2	T	Tensile	–252.8	422.0	523.3	204.8	1.3	0.95	1.21
5T6T1	T	Tensile	–252.8	421.3	496.4	159.3	0.7	0.88	1.08
T6T2	T	Tensile	–252.8	405.4	499.9	195.8	0.8	0.75	0.995

Table 2. AlBeMet162 tensile data at room temperature, –320 and –423 °F.

Other ID NO.	Orientation	Test Type	Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elastic Modulus (Msi)	1-in Elongation (%)	Plastic Elongation (%)	Total Elongation (%)
T6L1	L	Tensile	70	48.1	65.5	25.5	–	8.1	8.2
T2L5	L	Tensile	70	45.9	62.7	25.0	–	7.4	7.6
5T6L3	L	Tensile	70	46.1	61.9	26.1	–	6.3	6.5
5T6T4	T	Tensile	70	46.1	54.7	22.6	–	2.3	2.5
T6T5	T	Tensile	70	46.2	56.6	24.9	–	2.4	2.6
T2T3	T	Tensile	70	45.3	54.0	24.0	–	2.4	2.6
T6–45–1	45	Tensile	–320	45.0	66.2	34.5	2.7	2.5	2.7
T2–45–1	45	Tensile	–320	47.5	71.4	25.4	3.8	3.9	4.2
T6L2	L	Tensile	–320	52.6	76.9	25.6	3.1	3.3	3.6
T6L5	L	Tensile	–320	53.1	77.4	26.1	3.4	3.3	3.6
T2L3	L	Tensile	–320	50.4	74.7	31.4	3.1	3.1	3.3
5T6L1	L	Tensile	–320	51.5	69.0	27.1	2.9	1.9	2.2
5T6L4	L	Tensile	–320	55.7	62.0	27.3	0.6	0.8	1
T2T4	T	Tensile	–320	49.6	65.6	23.4	1.7	1.5	1.8
5T6T2	T	Tensile	–320	50.4	63.8	26.6	1.5	1.4	1.6
5T6T5	T	Tensile	–320	50.4	67.3	24.9	1.7	1.7	1.9
T6T3	T	Tensile	–320	50.3	69.0	27.5	2.0	1.8	2
T2T1	T	Tensile	–320	48.4	60.5	24.6	1.4	0.9	1.1
T2–45–2	45	Tensile	–423	63.7	77.8	25.6	1.5	1.06	1.36
T6–45–2	45	Tensile	–423	66.8	83.0	22.9	0.7	1.26	1.63
5T6–45–1	45	Tensile	–423	56.9	75.6	29.2	1.2	1.58	1.83
T6L3	L	Tensile	–423	68.8	77.9	25.4	–	0.62	0.92
T2L1	L	Tensile	–423	64.3	75.1	24.4	0.5	0.73	1.03
T2L4	L	Tensile	–423	65.3	83.9	32.1	1.3	1.44	1.7
5T6L2	L	Tensile	–423	63.9	76.7	29.1	0.8	0.88	1.15
5T6L5	L	Tensile	–423	69.2	80.4	23.1	1.1	0.92	1.26
T6L4	L	Tensile	–423	58.7	83.8	22.8	2.6	2.95	3.15
T2L2	L	Tensile	–423	67.1	80.3	26.7	1.1	1.05	1.3
T6T4	T	Tensile	–423	61.9	72.7	25.6	0.8	0.69	0.96
T2T5	T	Tensile	–423	62.9	74.3	23.0	–	0.64	0.96
5T6T3	T	Tensile	–423	62.8	75.7	28.9	0.8	0.75	1
T6T1	T	Tensile	–423	63.0	78.3	27.3	1.3	0.89	1.17
T2T2	T	Tensile	–423	61.2	75.9	29.7	1.3	0.95	1.21
5T6T1	T	Tensile	–423	61.1	72.0	23.1	0.7	0.88	1.08
T6T2	T	Tensile	–423	58.8	72.5	28.4	0.8	0.75	0.995



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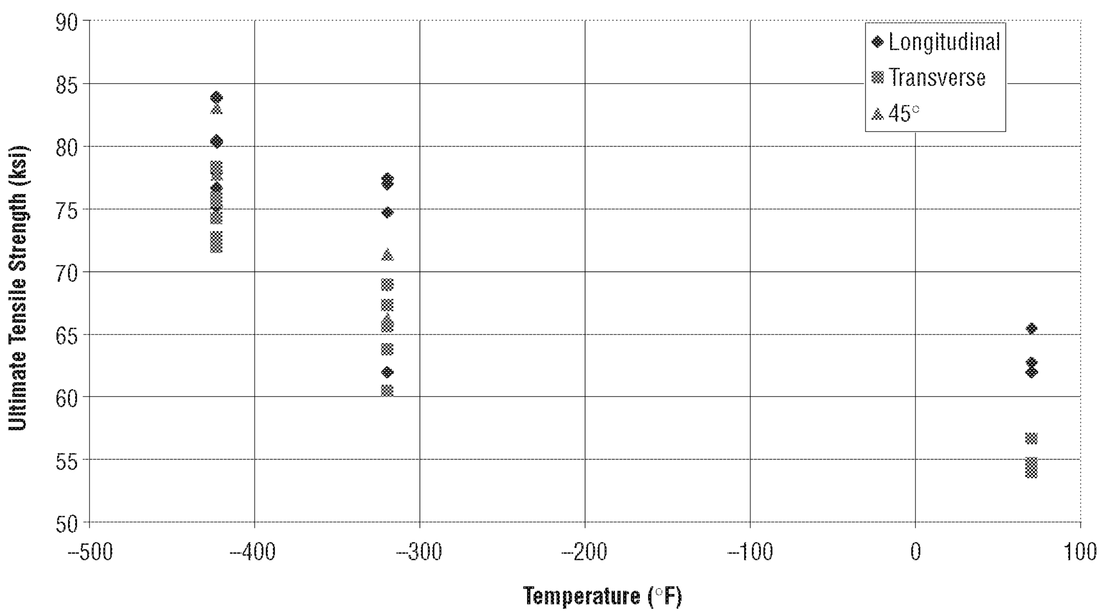
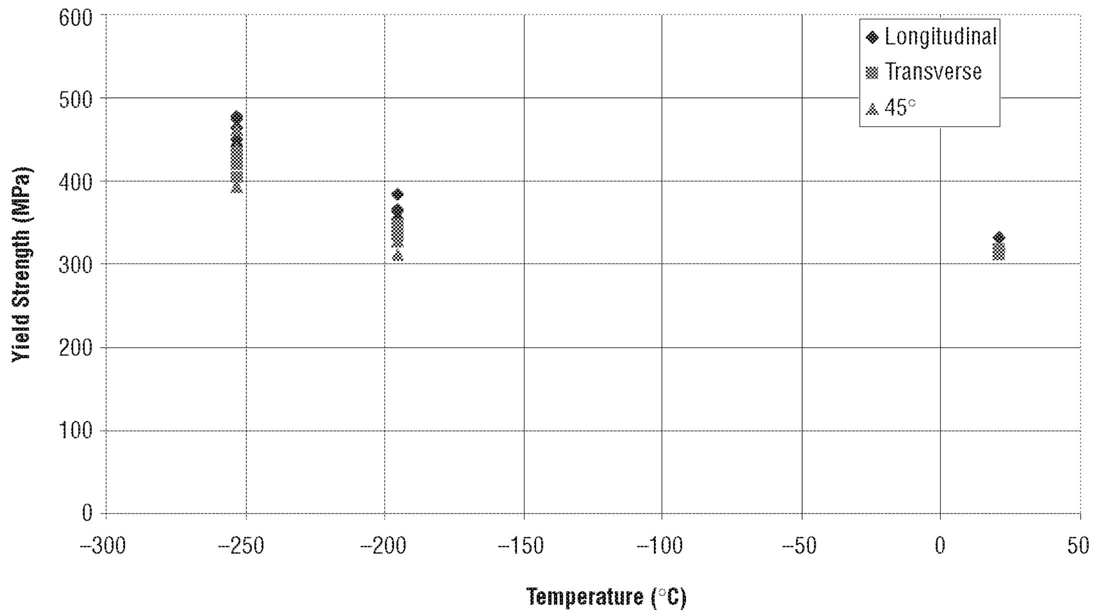


(b)

Figure 3. AlBeMet162 with (a) ultimate tensile strength (MPa) versus temperature (°C) and (b) ultimate tensile strength (ksi) versus temperature (°F).



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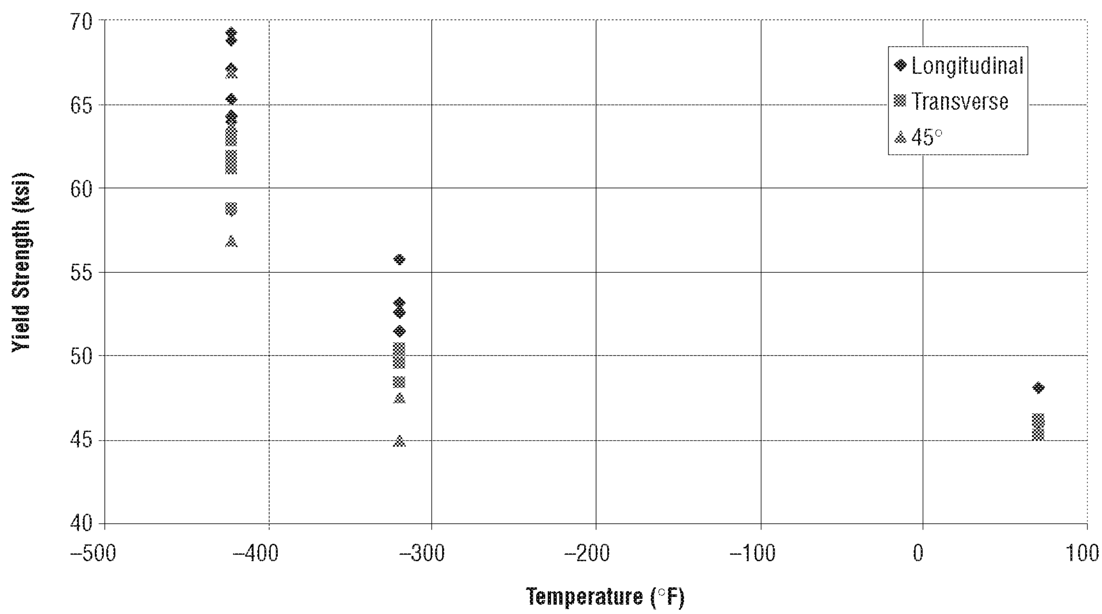
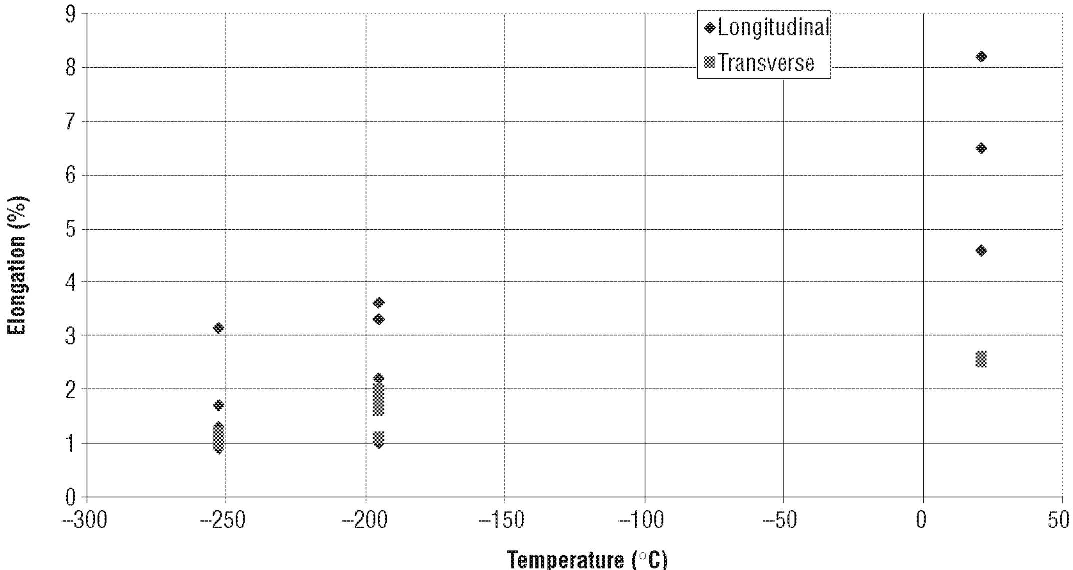


(b)

Figure 4. AlBeMet162 with (a) yield strength (MPa) versus temperature (ºC) and (b) yield strength (ksi) versus temperature (ºF).



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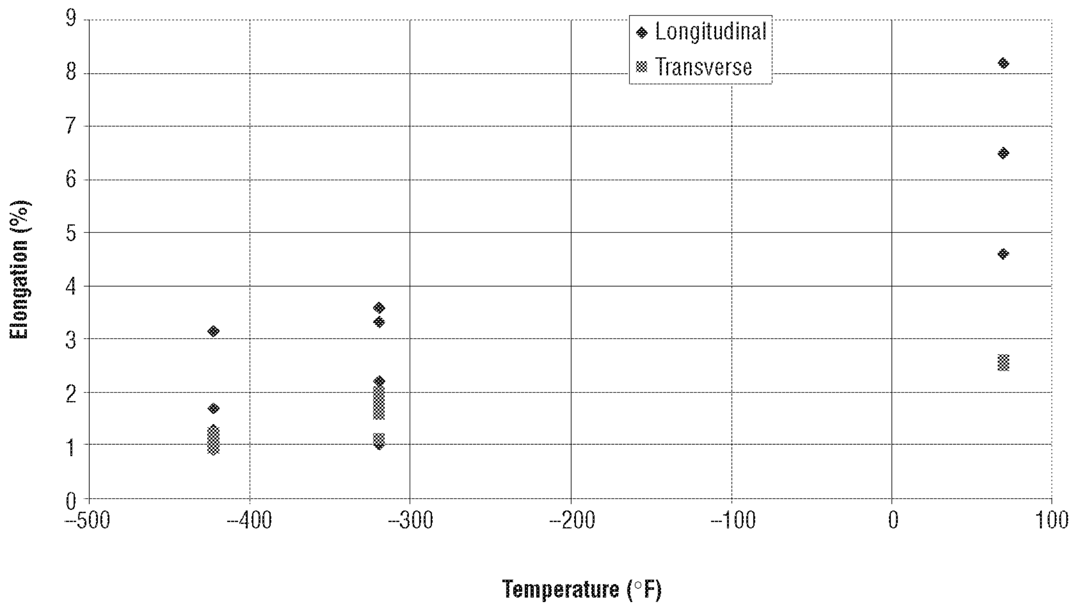


(b)

Figure 5. AlBeMet162 percent elongation versus (a) temperature (ºC) and (b) temperature (ºF).

Table 3. Mechanical property mean data summary.

Temperature °C	(°F)	Orientation	No. Specimens	Ultimate Tensile Strength MPa	(ksi)	Yield Strength MPa	(ksi)	Elongation (%)
–252.8	(–423)	L	7	549.5	(79.7)	450.2	(65.3)	1.50
–252.8	(–423)	T	7	513.7	(74.5)	425.4	(61.7)	1.05
–195.5	(–320)	L	5	496.4	(72.0)	363.4	(52.7)	2.70
–195.5	(–320)	T	5	449.5	(65.2)	343.4	(49.8)	1.70
21	(70)	L	3	437.1	(63.4)	322.0	(46.7)	6.40
21	(70)	T	3	379.9	(55.1)	316.5	(45.9)	2.60

Table 4. ANOVA results.

Treatment	Temperature °C	(°F)	α	Results
UTS–L/UTS–T	–252.8/–252.8	(–423/–423)	0.05	The means are statistically different
YS–L/YS–T	–252.8/–252.8	(–423/–423)	0.05	The means are statistically different
%e–L/%e–T	–252.8/–252.8	(–423/–423)	0.05	Cannot distinguish a difference in means at this α level
UTS–L/UTS–T	–195.5/–195.5	(–320/–320)	0.05	Cannot distinguish a difference in means at this α level
YS–L/YS–T	–195.5/–195.5	(–320/–320)	0.05	The means are statistically different
%e–L/%e–T	–195.5/–195.5	(–320/–320)	0.05	Cannot distinguish a difference in means at this α level
UTS–L/UTS–T	21/21	(70/70)	0.05	The means are statistically different
YS–L/YS–T	21/21	(70/70)	0.05	Cannot distinguish a difference in means at this α level
%e–L/%e–T	21/21	(70/70)	0.05	The means are statistically different
UTS–L/UTS–L	–252.8/–195.5	(–423/–320)	0.05	The means are statistically different
UTS–L/UTS–T	–252.8/–195.5	(–423/–320)	0.05	The means are statistically different
YS–L/YS–L	–252.8/–195.5	(–423/–320)	0.05	The means are statistically different
YS–L/YS–T	–252.8/–195.5	(–423/–320)	0.05	The means are statistically different
%e–L/%e–L	–252.8/–195.5	(–423/–320)	0.05	The means are statistically different
%e–L/%e–T	–252.8/–195.5	(–423/–320)	0.05	The means are statistically different
UTS–L/UTS–L	–195.5/21	(–320/70)	0.05	Cannot distinguish a difference in means at this α level
UTS–L/UTS–T	–195.5/21	(–320/70)	0.05	The means are statistically different
YS–L/YS–L	–195.5/21	(–320/70)	0.05	The means are statistically different
YS–L/YS–T	–195.5/21	(–320/70)	0.05	The means are statistically different
%e–L/%e–L	–195.5/21	(–320/70)	0.05	The means are statistically different
%e–L/%E–T	–195.5/21	(–320/70)	0.05	The means are statistically different

LEGEND:
UTS = Ultimate tensile strength
YS = Yield strength
%e = Percent elongation
L = Longitudinal specimen
T = Transverse specimen

Mechanical properties at room temperature met the requirements of specification AMS7912 for the ultimate tensile and yield strengths for both longitudinal and transverse specimens. The elongation met the specification requirement for the transverse specimens, but was below the requirement for two of the three longitudinal specimens. ANOVA performed on the room-temperature data showed that the ultimate tensile strength and percent elongation between the longitudinal and transverse specimen orientations are distinguishable, whereas the yield strength between these two orientations was not distinguishable statistically. This was consistent with the properties listed in the specification for these two orientations.

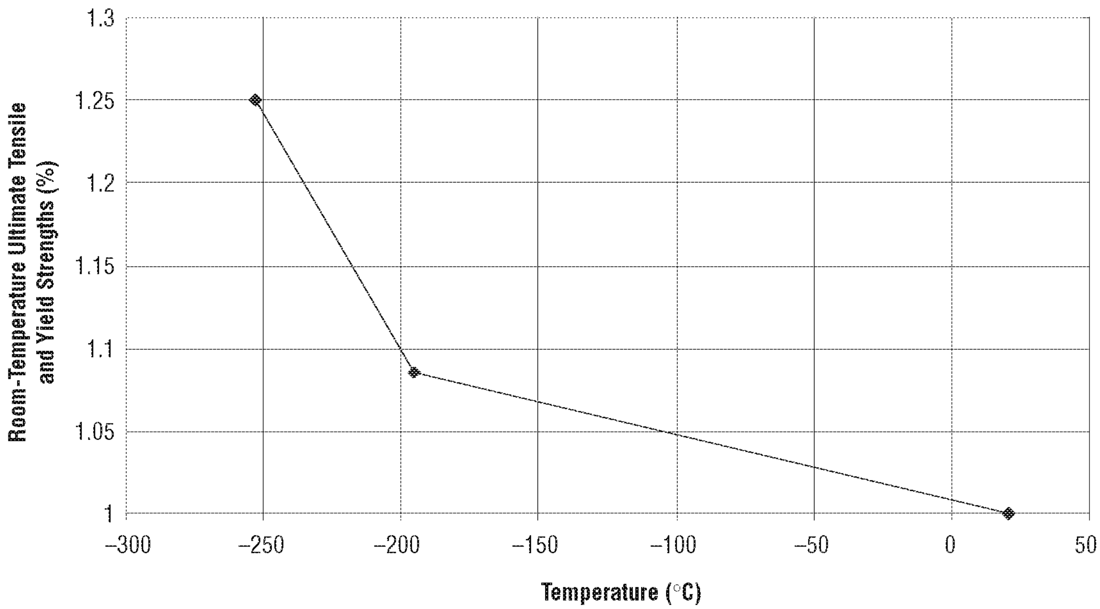
The ultimate tensile and yield strength at –195.5 °C (–320 °F) were increased over the room-temperature mechanical properties. ANOVA performed on the –195.5 °C (–320 °F) data showed the ultimate tensile strength and percent elongation were not distinguishably different between the longitudinal and transverse orientations, but the yield strengths were distinguishable statistically. ANOVA showed the –195.5 °C (–320 °F) properties were distinguishably different from the room-temperature properties in all cases except for the ultimate tensile strength–L orientation. For this case, the difference in means between –195.5 °C (–320 °F) and 21 °C (70 °F) was large, and one would expect a statistical difference in means. The reason the means were not distinguishable was because of the extremely large variance in the –195.5 °C (–320 °F) data.

The ultimate tensile and yield strengths at –252.8 °C (–423 °F) were increased over the –195.5 °C (–320 °F) and room-temperature mechanical properties. ANOVA performed on the –252.8 °C (–423 °F) data showed the ultimate tensile and yield strengths were distinguishably different between the longitudinal and transverse orientations, but the percent elongation was not distinguishable statistically. ANOVA showed the –252.8 °C (–423 °F) properties were distinguishably different from the –195.5 °C (–320 °F) properties in all cases.

Design values for the ultimate tensile and yield strengths versus temperature were generated from the mechanical property data and are shown in figure 6. The design properties are presented as ratios of the minimum cryogenic temperature ultimate tensile and yield strength values obtained during testing divided by the AMS7912 transverse room-temperature property. Figure 6 data represent lower bound properties for both the longitudinal and transverse directions. They do not represent A- or B-basis properties. To obtain cryogenic properties, multiply the AMS7912 room-temperature ultimate tensile or yield strength value by the percentage shown in figure 6.

Design values for percent elongation are shown in figure 7. These values are based on the AMS7912 value for room temperature, and on the minimum values obtained during testing at –195.5 °C (–320 °F) and –252.8 °C (–423 °F). Note the poor ductility at –195.5 °C (–320 °F) and –252.8 °C (–423 °F).

Modulus values shown in tables 1 and 2 are typical values based on tensile test results.



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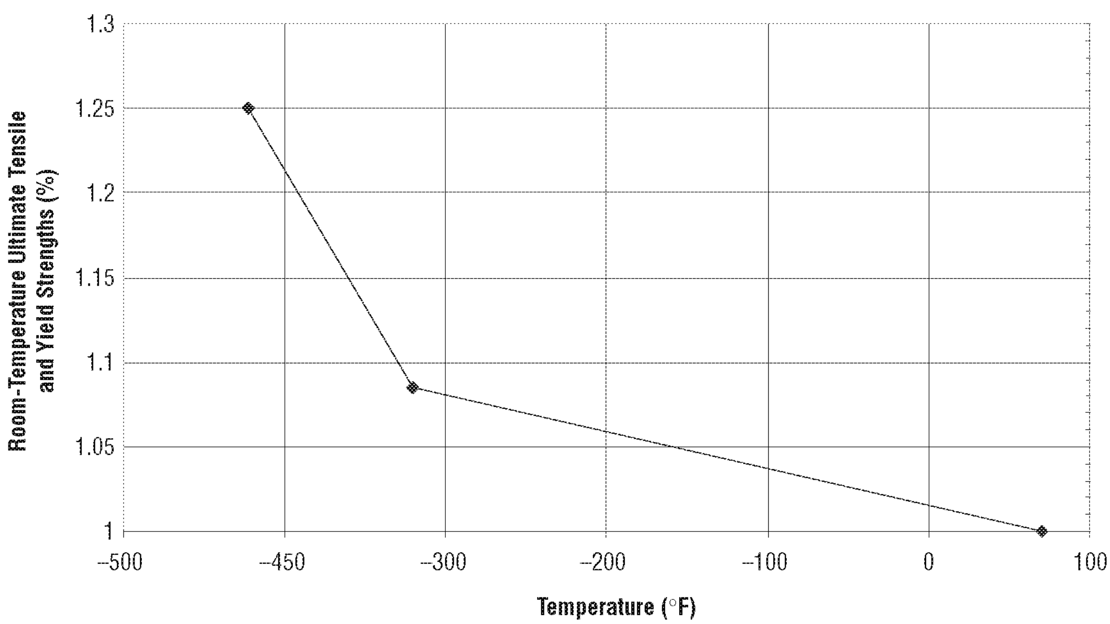
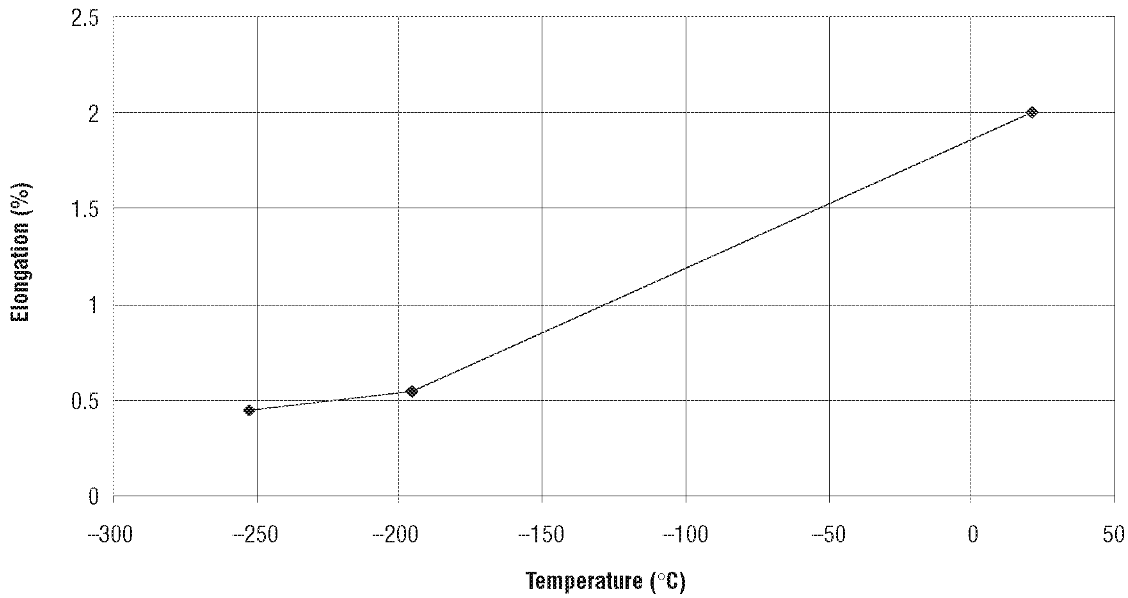
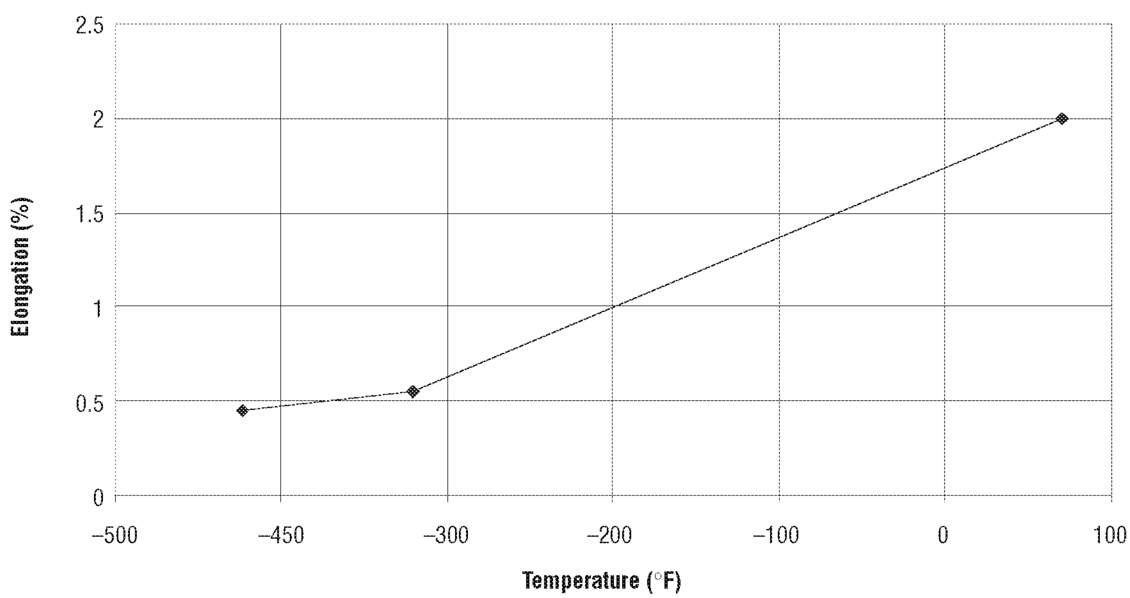


(b)

Figure 6. AlBeMet162 design properties for ultimate tensile strength and yield strength versus (a) temperature (ºC) and (b) temperature (ºF).



(a)



(b)

Figure 7. AlBeMet162 design properties for percent elongation versus (a) temperature (ºC) and (b) temperature (ºF).

4. CONCLUSIONS

The ultimate tensile and yield strengths for extruded AlBeMet162 material increase with decreasing temperature. The percent elongation for extruded AlBeMet162 material decreases with decreasing temperature.

At cryogenic temperatures, the ultimate tensile and yield strengths are higher in the longitudinal direction than the long-transverse direction. This is consistent with the room-temperature mechanical property data of AMS7912. At cryogenic temperatures, it is not possible to distinguish a difference in percent elongation between the longitudinal and long-transverse directions, whereas there is a difference in percent elongation at room temperature per AMS7912.

The ultimate tensile and yield strengths at –252.8 °C (–423 °F) are higher than these properties at –195.5 °C (–320 °F). The ultimate tensile and yield strengths at –195.5 °C (–320 °F) are higher than these properties at 21 °C (70 °F). The elongations at –252.8 °C (–423 °F) and –195.5 °C (–320 °F) are lower than the elongation at room temperature.

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Basic mechanical properties; i.e., ultimate tensile strength, yield strength, percent elongation, and elastic modulus, were obtained for the aluminum-beryllium alloy, AlBeMet162, at cryogenic (–195.5 °C (–320 °F) and –252.8 °C (–423 °F)) temperatures. The material evaluated was purchased to the requirements of SAE–AMS7912, “Aluminum-Beryllium Alloy, Extrusions.”

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